RF Matching Network Software

Calculations using ADLAB

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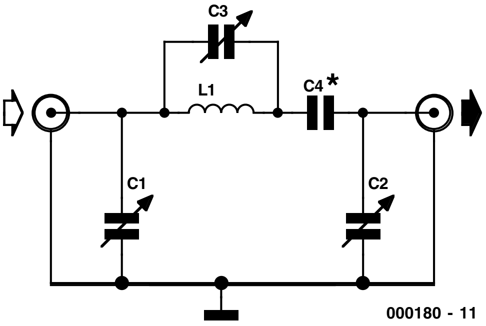
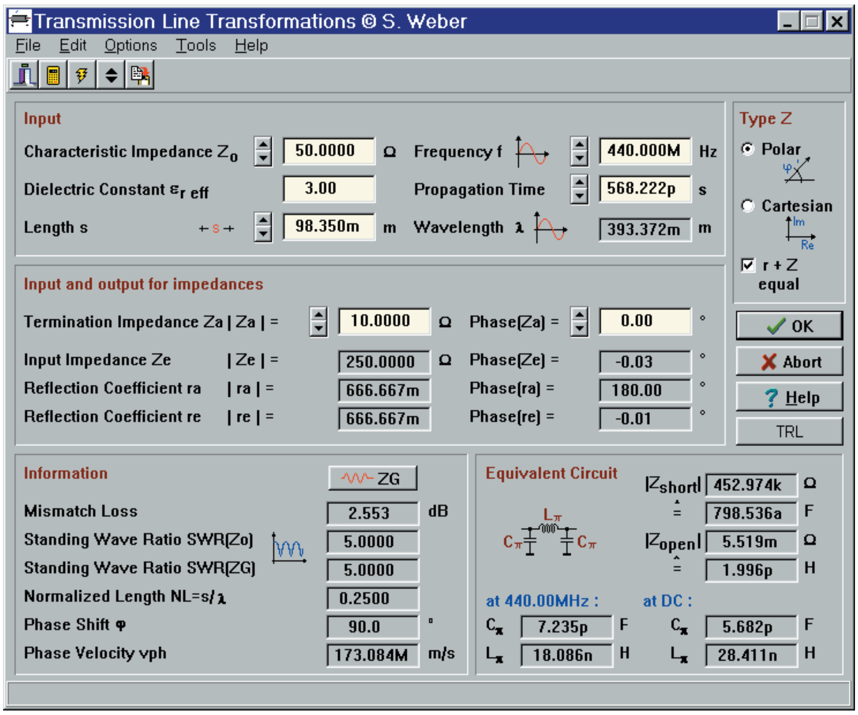
The universal RF matching network described in this article is particularly easy to use, adapt using (free) software and last but not least, easily constructed from readily-available components. We give example component values suitable for use in the 70 cm (440 MHz) band.

Matching networks are used in RF design to avoid mismatch where different impedances are involved. Calculation of component values is in practice left to a dedicated program such as the ADLAB shareware package used here. This package was developed by the author and is available for download from his website.



* optional

Figure 1. Complete circuit (C4 optional).



Transmission Line Transformations © S. Weber

Input

Characteristic Impedance Z_0: 50.0000 Ω

Frequency f: 440.000M Hz

Dielectric Constant $\varepsilon_{r\,eff}$: 3.00

Propagation Time: 568.222p s

Length s: 98.350m m

Wavelength λ: 393.372m m

Type Z

● Polar

○ Cartesian

☑ r + Z equal

Input and output for impedances

Termination Impedance Za | Za | = 10.0000 Ω Phase(Za) = 0.00 °

Input Impedance Ze | Ze | = 250.0000 Ω Phase(Ze) = -0.03 °

Reflection Coefficient ra | ra | = 666.667m Phase(ra) = 180.00 °

Reflection Coefficient re | re | = 666.667m Phase(re) = -0.01 °

Information

Mismatch Loss: 2.553 dB

Standing Wave Ratio SWR(Zo): 5.0000

Standing Wave Ratio SWR(ZG): 5.0000

Normalized Length NL=s/λ: 0.2500

Phase Shift φ: 90.0 °

Phase Velocity vph: 173.084M m/s

Equivalent Circuit

L_π, C_π, C_π

$|Z_{short}|$ 452.974k Ω

$\hat{=}$ 798.536a F

$|Z_{open}|$ 5.519m Ω

$\hat{=}$ 1.996p H

at 440.00MHz :

C_π 7.235p F

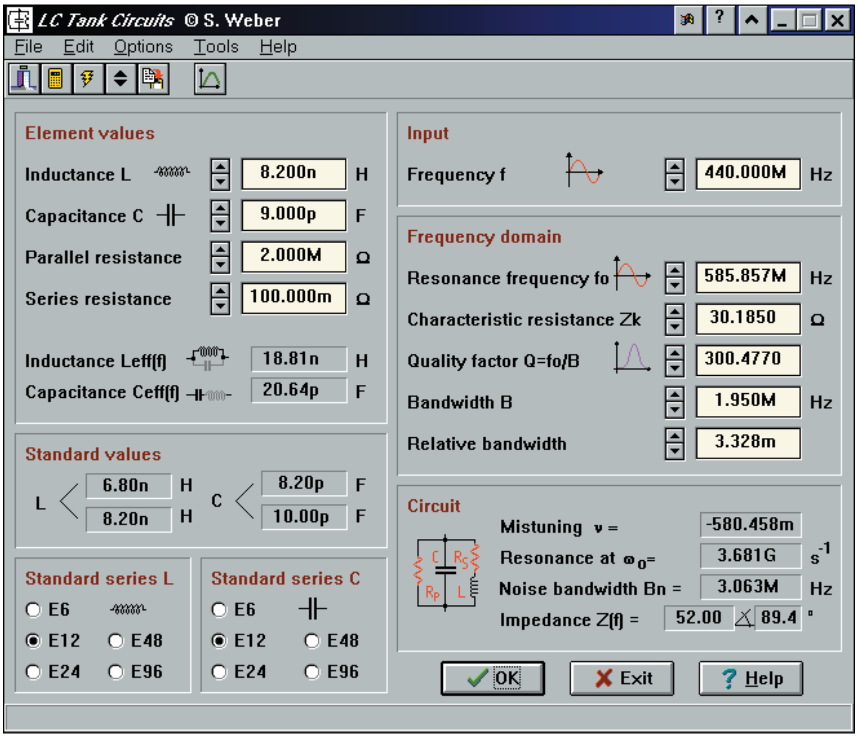
L_π 18.086n H

at DC :

C_π 5.682p F

L_π 28.411n H

Figure 2 : Equivalent circuit of a 50Ω λ/4 transmission line at 440MHz (calculation with LTRANS : L_1=18,08nH, C_1=C_2=7,235pF)



Element values
Inductance L: 8.200n H
Capacitance C: 9.000p F
Parallel resistance: 2.000M Ω
Series resistance: 100.000m Ω
Inductance Leff(f): 18.81n H
Capacitance Ceff(f): 20.64p F

Standard values
L: 6.80n H / 8.20n H
C: 8.20p F / 10.00p F

Standard series L
○ E6
● E12 ○ E48
○ E24 ○ E96

Standard series C
○ E6
● E12 ○ E48
○ E24 ○ E96

Input
Frequency f: 440.000M Hz

Frequency domain
Resonance frequency fo: 585.857M Hz
Characteristic resistance Zk: 30.1850 Ω
Quality factor Q=fo/B: 300.4770
Bandwidth B: 1.950M Hz
Relative bandwidth: 3.328m

Circuit
Mistuning v = -580.458m
Resonance at ω_0= 3.681G s^{-1}
Noise bandwidth Bn = 3.063M Hz
Impedance Z(f) = 52.00 ∠ 89.4 °

Figure 3 : Calculation of the effective inductance of a parallel LC circuit (LCFILT from Elekta Professional : 8,2nH||9pF results in 18,8nH at 440MHz).

Low-Pass Structure

A low-pass structure was chosen for the example matching network described in this article. This has the normally desirable side-effect that harmonics are attenuated. DC is passed with unity gain; if this is not desired, a suitably large series capacitor can be added to the circuit. In order to accommodate virtually any impedance combination, three alignment points are provided in the form of standard trimmer capacitors. **Figure 1** shows the complete circuit, which comprises a third-order elliptic low-pass filter. Construction of the circuit depends on the frequency band it is intended for. It is advisable to build the circuit as small as possible in a metal enclosure using SMA connectors, attaching the components to one another directly by their leads. For higher power applications, N-type connectors are recommended, along with air-dielectric trimmers with an adequate plate gap.

Component Values

The circuit is similar to the equivalent circuit of a transmission line, and indeed it is well known that a λ/4 line can be used to make a good matching circuit. The equivalent circuit of the λ/4 transmission line for the frequency band of interest gives us a good starting point for calculating the component values for our circuit. For the 70 cm band the relevant values are shown in **Figure 2**.

Trimmers C1 and C2 should be chosen to have a maximum capacitance of about three times the calculated value of 7.2 pF. L1 should be about half the calculated value (here 8.2 nH instead of 18 nH) since the effective inductance is increased by the parallel capacitance C3. C3 should be the same value as C1 and C2.

The value of C4 should be at least five times the value of C1. If a very large value, say 470 nF, is chosen (to extend the lower limit of the passband), a ceramic capacitor of around 470 pF should be added in parallel. If the circuit is to be modified for the 2 m or FM bands, the calculations can be carried out from scratch or the component values can simply be scaled. For example, for the FM band, all the capacitance and inductance values should simply be multiplied by 440 MHz / 100 MHz = 4.4.

Alignment

It might be thought that with three trimmers alignment of the circuit will be complicated. However, the situation can be simply illustrated in the Smith chart of **Figure 4**. If all three trimmers are set to their mid-positions, we know that the circuit will behave approximately like a λ/4 transmission line, with both an input impedance and an output impedance of 50 Ω. Thus these settings make a good starting point.

However, in contrast to a transmission line, the frequency response of the circuit is not periodic: instead it exhibits a low-pass characteristic (**Figure 5**). Here the second harmonic is attenuated by 14 dB.

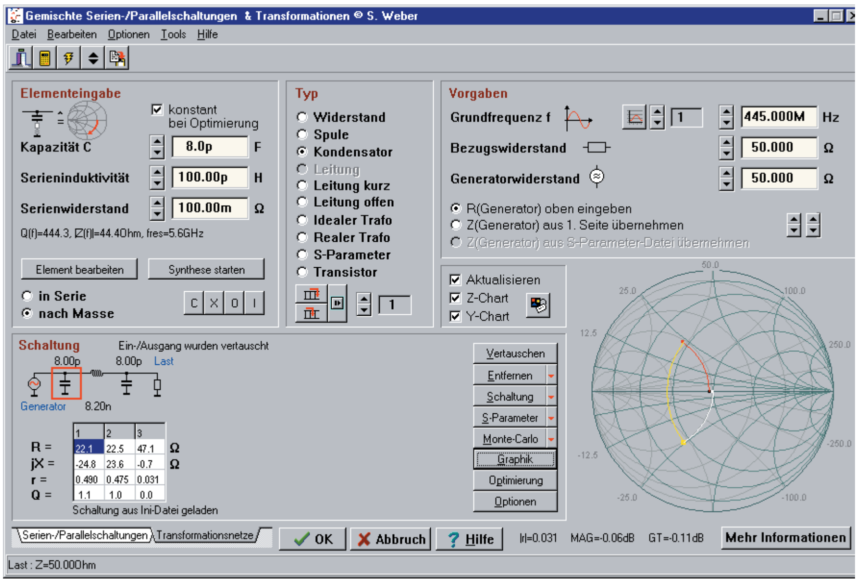
With the aid of the Smith chart we can see the effect of adjusting the values. We discover that C3 chiefly affects the real part of the impedance, while C1 and C2 affect the imaginary part. In practice we start from the basic settings above and adjust the trimmers in turn, beginning with the one that has the greatest effect. If the required impedance is already known (for example if it has been measured using a network analyser), the component values can be got directly from the Smith chart and the trimmers set appropriately. Final adjustments can then be made on the actual circuit.

Although the bandwidth shown in Figure 5 is rather wide, it narrows considerably when a large shift in impedance is required. **Figure 6** shows an example where an 8 Ω signal generator is to be matched to a 50 Ω impedance (VSWR 6.25:1). A small mismatch of 1.45:1 remains, since in practice the trimmers cannot be adjusted down to zero. Nevertheless, the resulting attenuation is only 0.3 dB (compared to 3.3 dB without a matching network). The –1 dB bandwidth is reduced to around 200 MHz and attenuation of harmonics is improved, especially above 1.5 GHz.

For many required impedances there are various combinations of trimmer settings with the same matching effect at the design frequency. These settings will, however, produce different characteristics in terms of bandwidth and harmonic attenuation. When used in conjunction with a power amplifier, one setting may be as good as another, although the resulting efficiency can vary. If C3 is given a high value, the frequency response falls off more steeply, because of the zero introduced into the response by the parallel resonant circuit. Smaller capacitors result in a flatter response and a wider bandwidth, and make the circuit less sensitive to component tolerances.

The component values used were:

Figure 4 : Circuit with its default values in the Smith diagram (calculation with CSERPAR).


Gemischte Serien-/Parallelschaltungen & Transformationen © S. Weber

Elementeingabe
☑ konstant bei Optimierung
Kapazität C: 8.0p F
Serieninduktivität: 100.00p H
Serienwiderstand: 100.00m Ω
Q(f)=444.3, |Z(f)|=44.40hm, fres=5.6GHz
○ in Serie
● nach Masse

Typ
○ Widerstand
○ Spule
● Kondensator
○ Leitung
○ Leitung kurz
○ Leitung offen
○ Idealer Trafo
○ Realer Trafo
○ S-Parameter
○ Transistor

Vorgaben
Grundfrequenz f: 445.000M Hz
Bezugswiderstand: 50.000 Ω
Generatorwiderstand: 50.000 Ω
● R(Generator) oben eingeben
○ Z(Generator) aus 1. Seite übernehmen
○ Z(Generator) aus S-Parameter-Datei übernehmen
☑ Aktualisieren
☑ Z-Chart
☑ Y-Chart

Schaltung Ein-/Ausgang wurden vertauscht

	1	2	3	
R =	22.1	22.5	47.1	Ω
jX =	-24.8	23.6	-0.7	Ω
r =	0.490	0.475	0.031	
Q =	1.1	1.0	0.0	

Schaltung aus Ini-Datei geladen

|r|=0.031 MAG=-0.06dB GT=-0.11dB

Last : Z=50.000hm

L1 = 8.2 nH (air core; approximately 3 turns 0.5 mm enamelled copper wire; internal diameter 2.5 mm)

C1 = C2 = C3 = 1-22 pF

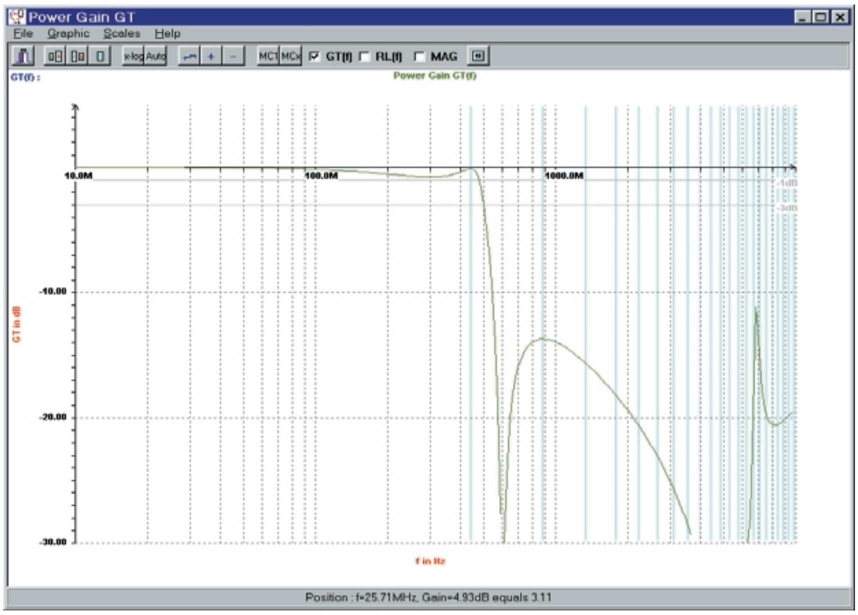
C4 = 470 pF

Application Example

Matching networks are frequently used with RF amplifiers or antennas. One application might be to match a small 70 cm handheld transceiver to an RF transmit amplifier. Without matching, the transceiver will not be able to drive the amplifier adequately: with a direct 50 Ω connection the output power will be unsatisfactorily low, and the automatic transmit/receive switch (VOX) may no longer work. The matching circuit can be fitted between the transceiver and the amplifier and the trimmers adjusted for maximum output power into the antenna. Adjust the trimmers in small increments, because when the trimmers are at the end of their travel a small movement can easily make matching worse rather than better. Take particular care when working with RF power amplifiers, which can be destroyed in cases of extreme impedance mismatch.

(0000180-1)

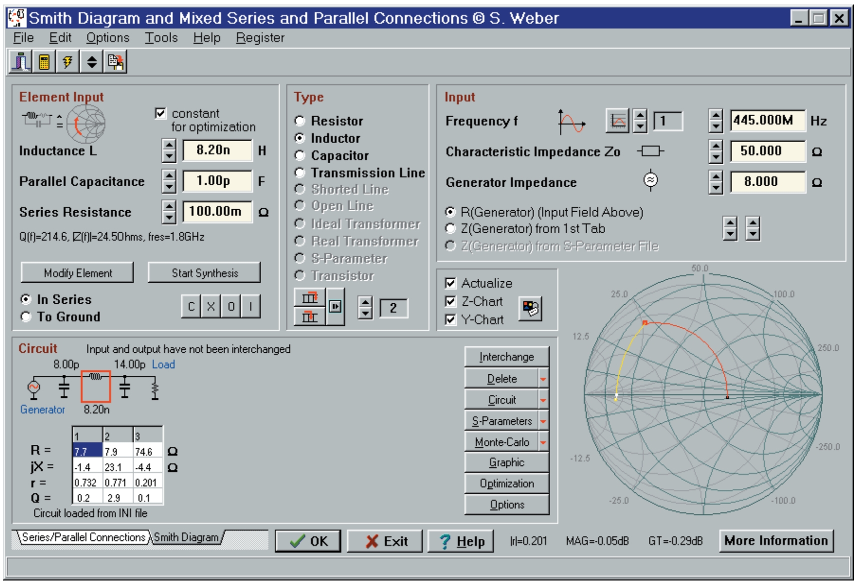
Figure 5 : Frequency response with default values (calculation with CSERPAR).


Power Gain GT

Position : f=25.71MHz, Gain=-4.93dB equals 3.11

The ADLAB software package, developed by the author, consists of eleven programs. It can be downloaded free of charge from http://home.t-online.de/home/weberconnect/adlab2.htm
This shareware version will run 100 times; the registration fee is US$ 35 for the unrestricted version.

Figure 6. Circuit adjusted for matching between 8 Ω and 50 Ω (calculated using CSERPAR).


Smith Diagram and Mixed Series and Parallel Connections © S. Weber

Element Input
☑ constant for optimization
Inductance L: 8.20n H
Parallel Capacitance: 1.00p F
Series Resistance: 100.00m Ω
Q(f)=214.6, |Z(f)|=24.50hms, fres=1.8GHz
● In Series
○ To Ground

Type
○ Resistor
● Inductor
○ Capacitor
○ Transmission Line
○ Shorted Line
○ Open Line
○ Ideal Transformer
○ Real Transformer
○ S-Parameter
○ Transistor

Input
Frequency f: 445.000M Hz
Characteristic Impedance Zo: 50.000 Ω
Generator Impedance: 8.000 Ω
● R(Generator) (Input Field Above)
○ Z(Generator) from 1st Tab
○ Z(Generator) from S-Parameter File
☑ Actualize
☑ Z-Chart
☑ Y-Chart

Circuit Input and output have not been interchanged

	1	2	3	
R =	7.7	7.9	74.6	Ω
jX =	-1.4	23.1	-4.4	Ω
r =	0.732	0.771	0.201	
Q =	0.2	2.9	0.1	

Circuit loaded from INI file

|r|=0.201 MAG=-0.05dB GT=-0.29dB